THE NEW SCIENCE
of
LIGHTING

by
MATTHEW LUCKIESH
and
FRANK K. MOSS
Lighting Research Laboratory

INCANDESCENT LAMP DEPARTMENT
GENERAL ELECTRIC
COMPANY
NELA PARK ENGINEERING DEPARTMENT
Cleveland

The New Science of Lighting

By M. LUCKIESH and FRANK K. MOSS

For years we have been presenting the results of scientific researches which have extended the viewpoint of lighting and vision into seeing as an activity of human beings operating as human seeing-machines. In fact, these researches have established important parts of the new science of seeing. In parallel with the publication of new scientific data and principles we have presented a series of papers interpreting the new knowledge and viewpoint into lighting. Admittedly, light is produced and used for the purpose of seeing, but it has not been specified on a sound scientific basis. The new science of seeing provides new knowledge and a new viewpoint upon which the specification of light and lighting may be founded. Much new knowledge is still needed. In fact, no more than a sound beginning has been made. However, from the new science of seeing a new science of lighting is already evolving. Light and lighting are the most universally controllable factors in seeing. This accounts for the new interest and importance which the science of seeing gives to lighting practice. We believe that a recapitulation is more desirable at the present time than additional data and interpretations. Therefore, the present paper is an attempt to reduce a very complex subject into a brief, readable sketch of the newly-extended viewpoint. We also have included brief glimpses of major facts and principles which reveal the opportunity and the pathway for lighting to evolve from a crude art into a sound science. In this sense, this paper sketches the most important period in the evolution of lighting practice.

THE artificial world which mankind has been building for many thousands of years is the product of knowledge—and of ignorance. It is a complex structure arising out of a desire to be independent of Nature's obvious vagaries, uncertainties and burdens. Many forces have been at work in its construction and, in the absence

---

A paper presented before the Twenty-eighth Annual Convention of the Illuminating Engineering Society, Baltimore, Md., October 1–4, 1934, Lighting Research Laboratory, General Electric Company, Cleveland, Ohio.

of adequate knowledge, it is not surprising that some of these are inconsistent and conflicting. Scientific method is a very recent invention and modern science as a movement got seriously under way only a century or two ago. Before the advent of scientific method all knowledge was gained by the often painful process of accidental experience or, at best, by the tedious and groping method of trial and error. These unscientific approaches to the unknown are still far more prevalent than the modern scientific method of systematic approach. They are not only inefficient methods but they are ineffective in revealing the unobvious. In fact, perhaps the most outstanding characteristic of modern scientific method is that it reveals the unobvious. For example, it has discovered, measured and harnessed the electron, which is beyond the reach of human senses. It has done so with hidden natural laws and forces. On every hand it is unraveling the unobvious unknown.

Civilization has been a going concern, although an unscientific one, for thousands of years before the recent advent of modern science. It was inevitable that many practices were born and developed before adequate knowledge was available. Therefore, modern science, which is commonly considered a vanguard of civilization, actually has a far greater responsibility at the present time in performing rearguard services. As a vanguard service, modern science can supply knowledge for new construction. However, as a rearguard it must dictate the revision of erroneous practices which have been founded upon misconceptions and false assumptions due to inadequate knowledge. In the past an essential activity or practice necessarily began as a crude art. Through the inefficient process of every-day experience it might evolve into a stage of empirical practice. Eventually scientific research can supply the knowledge which finally evolves it into a science. Then many surprises are likely, for only through the application of scientific method are the deeply hidden and unobvious facts revealed. Lighting is a typical and outstanding example of the natural course of evolution. Only recently has modern science begun to reveal deeply hidden effects of lighting and facts of seeing.

In the course of civilized progress increased burdens go hand in hand with increased convenience and comfort. Artificial conditions are substituted for natural ones without full knowledge of the consequences. Mankind came indoors and imposed new tasks and new environments.[1] It was obvious to human beings that they needed light, but unobvious penalties remained hidden. Modern civiliza-

tion has imposed upon eyes and human seeing-machines unnaturally severe prolonged critical visual tasks under greatly restricted light and altered lighting.[2] Hours of close work are now the rule under meager light and unnatural lighting for eyes and human beings that evolved under an abundance of natural light outdoors when close visual work was casual. Convergence of eyes requires effort and so does concentration of attention. Abnormal visual tasks under subnormal conditions is a combination of circumstances worthy of deep suspicion. This and many other facts and analyses eventually led us to develop a new and extended viewpoint which, in turn, opened a new vista of research. The chief result has been the development of the new science of seeing from which is being born a new science of lighting.

For many years we have published the results of researches and analyses[3] which have gradually given form to a new scientific structure appropriately termed *the science of seeing.* Inasmuch as light and lighting are essential and controllable tools for seeing, much of the new knowledge of seeing also provides a foundation for a science of lighting for seeing. The science of seeing includes much more than a science of lighting, but they go hand in hand a long way. For years we have tried to interpret the results of our researches in seeing[4] into lighting practice.[5] These interpretations introduce a new and adequate viewpoint for lighting practice and are establishing a solid foundation for a science of lighting. In fact, lighting practice has reached an important stage in its evolution. A research offensive of adequate scope is providing new knowledge which has placed lighting upon the threshold of its greatest opportunity for service to human beings. The most important period in the history of any civilized activity is that during which it emerges from a crude or empirical art into a science. We have definitely entered that period in lighting. Therefore, it seemed best to pause temporarily in the presentation of new data and interpretations and to present a more or less consolidated sketch of the new science of lighting.

BASICALLY NEW CONCEPTS

The science of seeing[6] was born of radically new concepts. A science of vision has been evolving for a long time but it deals with the eyes or, more broadly, the visual sense. The science of vision is concerned with the abilities and limitations of eyesight as a tool. Seeing involves this tool and another tool—lighting.[7] But seeing is much

more than this. It is an activity of human beings operating as *human seeing-machines.*[8] Seeing is work that a human being does. It requires lighting and vision but also human effort. It involves muscular activity, the nervous system, and mental reactions. In other words, seeing is an activity of the human body and mind. It utilizes human energy and other resources just as any other task does. These new concepts have opened a vast new vista for thought, research and analysis. They reveal the extreme narrowness and inadequacy of the older viewpoints and practices which were erroneously assumed to deal adequately with seeing. They have cleared the way for the development of a science of seeing which in turn is laying the foundation for a science of lighting.

The major new concepts have given rise to many others. The *human* seeing-machine no longer need be merely satisfied to barely see but has a right to see easily. Studies of vision are concerned with thresholds, that is with limiting visibility. As long as study and consideration were confined to vision, practices were more or less anchored to the realm of barely seeing. However, when seeing is properly considered as work which human beings do we are immediately concerned with seeing easily. Therefore, the science of seeing is concerned with optimum conditions for easy seeing instead of being confined to minimum conditions of barely seeing or threshold visibility.

This human aspect of seeing, firmly entrenched through the new conception of human seeing-machines, shows that old ideas must succumb to their own inadequacy. The efficiency of a worker is no longer measurable by the useful work he does per dollar or per hour. His welfare as a seeing-machine is determined by the useless work he does—not merely externally in blundering due to poor seeing but internally through waste of energy and other human resources. The difficulty of a visual task assumes a new importance. It is obvious that it is more difficult to see a small object of low contrast than a large one of high contrast. But no longer is this merely an external factor. The new viewpoint directs the attention to internal penalties paid by human seeing-machines. Research must relate the external visual tasks to the internal costs of seeing—and it is doing so. The science of seeing places lighting in the class of labor-saving devices and also elevates it to the level of things which affect the entire human being.

A new conception of the foot-candle became inevitable. As a physical unit it is fixed in value and this idea has been over-emphasized in

past practice. As a factor in seeing the foot-candle is not fixed.[9] Its value depends upon the conditions to which it is applied. A new scale of foot-candles arises from the science of seeing which reveals inconsistencies in the empirical foot-candle recommendations of the past. Furthermore, the new goal of seeing easily, instead of barely seeing, has revealed the necessity for an entirely new order of magnitude of foot-candle recommendations. Lighting of the past has been in competition with darkness. The new concepts place it in competition with daylight intensities. Recommendations of 5 or 10 foot-candles are ridiculously inadequate when researches in seeing indicate that 100 foot-candles for reading and 1000 foot-candles for sewing on dark goods are conservative from the viewpoint of easy seeing for human seeing-machines.[10]

The conception of the *human* seeing-machine requires revision of old ideas of visibility. A traffic sign or an advertisement on a billboard may have high visibility to a person doing nothing else but looking at it.[2] However, when that person is doing something else simultaneously, such as driving an automobile, his efficacy as a human seeing-machine is reduced. The science of seeing reveals that any other activity of a human being reduces his ability to see. Therefore, a new concept of visibility arises. A human seeing-machine, being human, has a certain total sense capacity. His efficacy as a seeing-machine depends upon how much of his sense-capacity is devotable to seeing.[11] Distractions of every kind must be taken into account in appraising seeing conditions. This applies to human beings in the work-world, in traffic or even when leisurely reading in their own libraries. The science of seeing has emphatically introduced the human element into seeing and therefore into lighting. Not only the physiological aspects but the psychological aspects assume a decisive importance.

The old ideas of visibility must be expanded to include seeing quickly, accurately and with certainty. The requirements should not be merely sufficient under ideal conditions. Factors of safety must be developed for seeing and for lighting just as they have been applied to inanimate things such as bridges, which are much less subject to vagaries, subtle influences and uncertainties than human seeing-machines.

Through the extension of our viewpoint and knowledge from vision into seeing the human being as a seeing-meter can be better appraised. It is a simple matter to note that an object is near the threshold of

visibility. For example, fine print or thread may be obviously difficult to see under a given condition. However, it is utterly impossible for human seeing-machines to determine the conditions under which they can see most easily. The costs or effects of seeing are so subtly hidden that they can only be revealed by careful and unique scientific research. In fact, they have long evaded the attention of scientists interested in vision or in lighting. The development and science of lighting must depend very much upon the foundations laid in the laboratory. This is true of other practices and lighting cannot be an exception. However, it is difficult for human beings to believe that they are not dependable seeing-meters.[10] The science of seeing has already adequately proved this and everyone for his own good must be convinced of this. No one thinks he is superior to a thermometer for measuring temperature or to a pair of scales for weighing a beefsteak. Still these are relatively much easier to appraise than lighting or seeing conditions—unless the latter are very bad. However, there is a long range from obviously poor lighting or seeing to the optimum conditions of best lighting or easiest seeing. This is a new realm opened recently by the science of seeing which must be relied upon to dictate the lighting.

The science of seeing reveals the necessity for high intensities of illumination but it also emphasizes the limitations of foot-candles. There is much more to lighting than light.[6] The visibility of objects depends upon lighting as well as light. The relatively new conception of lighting at its best being a combination of general and supplementary lighting, finds additional support in the need for such a system in order to obtain economically the high intensities now known to be desirable. However, this means that the lighting specialist must absorb and interpret the complex data dealing with *quality of lighting* and that research must establish new facts and principles.

New concepts have arisen pertaining to eyes and vision and much of the old data pertaining to them must be viewed and interpreted anew. Space does not permit discussing these here. However, the new science of seeing has revealed a new vista of opportunity and responsibility to eye-specialists. They become partners of lighting specialists through the partnership of lighting and vision.[12] The seeing specialist must evolve to serve a half-seeing world. Much new knowledge is already available for this evolution. Lighting and eye interests are already coöperating in the conservation of human resources through better seeing. They are bound to become closer in their activities.

Many other new concepts applicable to lighting for seeing arise from the new science of seeing. In this summary of the new science of lighting only glimpses can be presented. However, lighting interests may well develop a broader conception of lighting appropriate to the new practices which are being dictated by the science of seeing. Lighting is promoted to the same level of importance that vision has enjoyed. It becomes even a more important factor because of its controllability. The new science of lighting becomes a humanitarian movement which should engulf every human being. It becomes far more intimate than ever before with human efficiency and welfare. Thus the new conception makes it emphatically a part of social science. And finally as lighting evolves into a full-fledged science it becomes a profession. It cannot reach this status until its specifications are dictated by the courage born of incontestable knowledge.

FROM A CRUDE ART TO A SCIENCE

Lighting is a chain of three primary links. As shown in Fig. 1, they consist of

Production of light
Control of light
Specification of light and lighting.

The first two of these are sound physical sciences which have been evolving for many years. The third link has long been a makeshift—scarcely even a thoroughly empirical one and certainly not a scientific one. Lighting, as any other chain, is as weak as its weakest link.

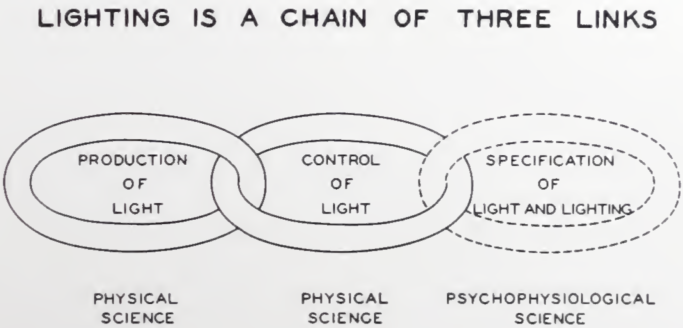

FIG. 1—The new science of seeing is providing a basis for the specification of light and lighting. It is forging the important link connecting light and lighting with human needs and welfare.

Without the science of seeing, the third, and most important link from the viewpoint of human interest, has existed only in the crudest form.

The great weakness in this chain readily explains the general lack of lighting consciousness, the low intensities of illumination still of the age of candles, the lack of confidence and power in lighting offensives, the vagueness of objectives, the inadequate enthusiasm for lighting, the presence of unnatural and even unreal obstacles, the general looseness of thinking and practice, the lack of coördinated offensive, the lack of recognition of lighting as a profession and in many cases the low grade of personnel which presumes to be expert in lighting. It even explains why almost everyone thinks he knows a good deal about lighting. Certainly seeing is as complex as the matters dealt with by medicine, ophthalmology and other professions which those in need of such services recognize as professions. Only when lighting becomes a science can it arise from its present status to the high plane it deserves in this complex civilization. Already the new science of lighting which is emerging from the science of seeing is having an influence upon the conditions briefly outlined in the foregoing.

The production and control of light are physical sciences. Engineering in its generally accepted sense is the application of physical science. With the lack of development of the third link—specification of light—which is a psychophysiological science, lighting had to be practiced as engineering. Lighting practiced as engineering falls far short of supplying light and lighting *best for human seeing-machines.* The sale of lighting has been handicapped by scanty knowledge of the needs of, and benefits to, purchasers and users of light. The science of seeing is supplying this knowledge by forging the specification link in the chain of lighting. What lighting can *do* for human beings can be *sold* to human beings.[13]

Let us take a lesson from the designer of a bridge. He designs for requirements. Knowing the span and the maximum load he computes the steel. He applies a sizable factor of safety to allow for uncertainties such as flaws in the steel members. He bases his specifications upon scientific knowledge and he will not retreat from them. He does not design a bridge to fit what a purchaser thinks he needs, nor does he base his technical design upon what he thinks he can sell. Lighting may never reach that stage of complete scientific specification; but that is the ideal goal. Scientific research works wonders and it is folly to predict what our knowledge will be in the future.

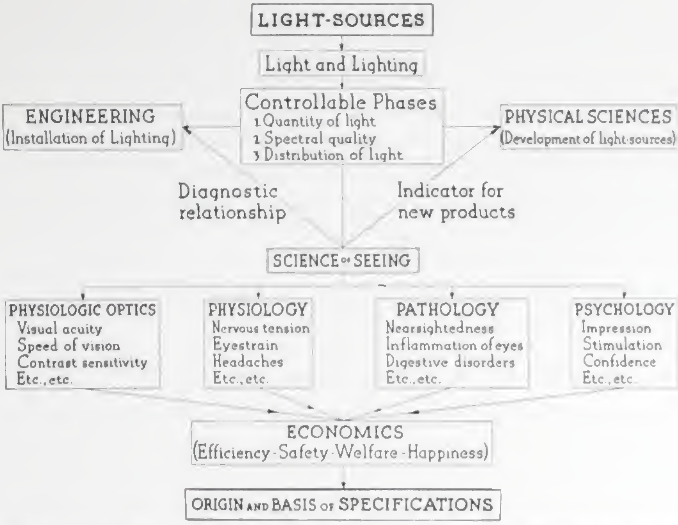

FIG. 2—The new science of seeing is more than a necessary foundation for a science of light utilization. Eventually, it should be the heart of the lighting art, extending influence to the development of light-sources and lighting equipment as well as to specifications of light and lighting.

At least we have taken the first decisive steps toward forging the link of specification of light and lighting. Many supporting data are in the offing. Complex though seeing is we are confident that a new science of lighting will rapidly develop now that the most difficult steps have been taken.

The contributions of the science of seeing to a science of lighting do not end with the forging of the third link—specification of light and lighting. It provides much foundational knowledge for the other two links—production (modification) and control of light. The science of seeing is the heart of lighting and therefore of the profession and businesses involved. Fig. 2 provides a diagrammatic view of the major technical phases of lighting, from light-sources to human beings and specification. From this diagram the new science of lighting can be developed and presented comprehensively. At one end of the lighting chain are light-sources. At the other are human beings. The end-products of lighting are human behavior, efficiency, safety, welfare and happiness. From these end-products, lighting must be appraised; and from the new economics, sales must be made. This is the proving ground for specifications of light and lighting regardless of their origin.

It is suggested that Fig. 2 be studied by beginning at the bottom and following each arrow independently.[13] The proper light-source may not be available. If not, this is a path which leads to the development of a proper light-source or to the modification of an available one. Eventually the lighting specification dictates the character of the installation. Finally, human seeing-machines are served and the results of this service provide a check on the satisfactoriness of the specifications. This is a brief glimpse of the procedure when lighting becomes a science. In many respects the picture is an idealistic one. But that is a worthy goal and scientific knowledge leads steadily toward it.

MAJOR FACTORS IN SEEING

The science of seeing involves three major and interdependent complexities. These are considered separately in order to avoid the difficulties which would be encountered in a discussion of the functioning of the human seeing-machine as a single complex process involving both physical and psychophysiological variables. Briefly, these three complexities involve, respectively,

The visual task
The visual sense
Psychophysiological effects of seeing.

The Visual Task[10]

Since factors which influence the visibility of objects are completely controllable in some cases and partially so in all cases, they are of basic importance in a science of seeing.[3] The factors commonly associated with visibility are the size of the object or of its critical details,[14] the level of brightness or illumination, the contrast in brightness and color, and the time required or available for seeing.[15] Extensive researches[16] have established the relationships which exist between these factors and these data permit quantitative analyses of various visual conditions. Contrast has been found to be a very important factor although it had been generally ignored in researches and practice. It is to be emphasized that these data are obtained from researches in the field of physiological optics and hence are to be considered in a relative rather than in an absolute sense. This is an inherent characteristic of all data of the science of seeing. Furthermore, such data are obtained only under threshold conditions of seeing and do not take

into account ease of seeing or the costs in energy and other human resources, of performing the work of seeing over a period of time.

From the viewpoint of improving conditions for seeing, the most important fact concerning these factors is that mutual relationships exist between them.[17] Therefore, by an augmentation of one factor it is possible to compensate for deficiencies in one or more of the other factors, provided that *all* factors are above certain limiting or threshold values. These threshold values have been determined with precision for subjects of normal vision. Usually, these threshold data are of theoretical rather than of direct practical interest since visual tasks are seldom accomplished or undertaken under such limiting and unfavorable conditions. In other words, good seeing requires a large factor of safety which elevates conditions far above the threshold whenever possible. However, the exceptions to this generalization may be extremely important. For example, in driving an automobile it may be necessary to perceive and to react to a visual stimulus of a duration which is of a threshold order. Likewise, in piloting a ship or airplane the visibility may be near the threshold due to fog, haze, or to other factors. In general, a consideration of threshold limitations of the visual sense is essential in situations which involve the safety of human beings.

Although accurate measurements pertaining to the visibility of objects have long been available, these data have been, until recently, of restricted value in improving conditions for seeing. In fact, due to over-emphasis and inadequate interpretation, such data have exerted a detrimental influence in many cases. Visibility measurements are possible only at threshold conditions for seeing. Such conditions are intolerable and, with few exceptions, are not encountered in practice. However, as long as scientific data were confined to the realm of barely seeing it is not surprising that lighting was considered satisfactory as long as it was generally better than that required for barely seeing.[2]

The science of seeing, by invading the psychophysiological realm of seeing, has been able to increase the significance and usefulness of visibility data by establishing correlations between threshold seeing and easy seeing.[10] The determination of the relative difficulty of various visual tasks becomes far more practicable if it can be done by utilizing visibility as a criterion than by any other known means. The science of seeing would advance slowly if, in everyday practice, it were necessary to determine the relative difficulty of various tasks or the contributions of various aids to seeing by any of the physiologi-

cal criteria, such as the development of nervous muscular tension, which involve tedious time-consuming laboratory technique. A very important contribution of the new science of seeing was the proof that an aid to seeing which was effective in lowering the visual threshold was likewise effective in increasing the ease of seeing when conditions for seeing were far above the threshold.[18]

The human being is a human *device* which does the seeing. Therefore, the visibility of an object depends upon the efficacy of the human seeing-machine.[10] Various factors affect this efficacy such as eye-defects or distractions. The visibility of an object is certainly higher when the human being knows the object is there and has nothing else to do but to look at it. Its visibility is much lower when the human seeing-machine is distracted by other objects in the visual field, by simultaneously performing other tasks, by noises[3] which impress themselves upon the attention and by other factors. Certainly the new conception of seeing and of human seeing-machines has introduced various *human* factors which necessitate a radical revision of older concepts. (See Fig. 3).

The difficulty of a visual task depends upon the fundamental factors associated with the object but is measured by the effects upon the human being which is doing the seeing. The final end-products of the effects of seeing are expenditures of human resources.

Demonstrations of the facts established by tedious laboratory researches are difficult because of the very reason that laboratory experiments are tedious. They require a vast number of observations because of the flexibility or fluctuations in vision and in attention. However, some demonstrations have been devised by taking advantage of recently acquired knowledge.

The Visual Sense

A clearer concept of seeing, as a universal activity of human beings operating as seeing-machines, evolved when light as well as eyes was given primary consideration. This transition emphasized the importance of light and lighting to the eye specialist as tools for preventing or minimizing the waste of human resources expended in seeing. Thus thousands of potential *seeing-specialists* become available to a half-seeing world. In general, the transition is from eyes and vision to seeing and human beings operating as seeing-machines. The science of seeing introduces eye-specialists more definitely into the new

age of prevention. They should be powerful factors in the application of the new science of lighting. Certainly they welcome the opportunity for even greater service than supplying crippled eyes with crutches.

An appreciation of the adaptability of the eyes[19] to various conditions for seeing leads directly to the minimization or elimination of many abuses imposed on the visual sense. The science of seeing introduced experiments which proved that the ability to perform a visual task under certain conditions was not necessarily an indication that the conditions were satisfactory to the eyes. Thus, production of work, which has been a criterion for dictating the conditions under which exacting seeing was done,[20] is no longer a logical or justifiable criterion. These experiments clearly indicated that the eyes were frequently penalized by their willingness and ability to function under handicaps. Experiments which seek to indicate the relative influence of various conditions for seeing by measuring production are usually significant only when the subjects are expending the maximum energy and are near the point of exhaustion. This is a rare condition and unjustifiable excepting in emergencies.

Statistical analyses of the prevalence of defective vision establish the fact that the eyes become defective through age, use and abuse.[2] It is apparent from these data that although the eyes have the ability to compensate for severe or unnatural visual conditions, they are eventually injured in doing so.[3] That the eyes are slow to complain of abuse is a fundamental reason why a consciousness of the costs of seeing would be a valuable asset to a half-seeing world. In this connection it might be well to consider how deeply hidden some of the far-reaching effects of seeing have been until recent new research technique has revealed them. This is likely as true of effects upon the eyes and visual sense.

Ophthalmology has developed an exact science for the appraisal of the capabilities and limitations of individual eyes. The sciences of optometry, medicine, therapy and surgery seek primarily to correct ocular defects rather than to prevent them. Among the more recent fundamental scientific developments is the emphasis that differences in the size and location of the retinal images are responsible for certain aspects of so-called defective vision. It is probable that such defects would be much less serious if seeing were limited to easy and natural tasks. The science of seeing also includes the appraisal of

the limitations of individual eyes and seeks to compensate for such deficiencies by specifying optimum conditions for seeing.

Since higher levels of illumination contribute to clearer or easier seeing, it seemed reasonable to assume that persons possessing the lower retinal sensibility would have the larger natural pupils. A recent investigation indicates that this assumption is correct.[21] Such evidence of Nature's attempt to compensate for visual deficiencies is an indication of the need for giving the eyes the maximum assistance for the performance of the abnormally severe visual tasks imposed by civilization. The pupil is the only part of the mechanism of the eye which visibly changes due to a change in the seeing conditions. Therefore, the new science of seeing has emphasized the importance of data pertaining to pupil size. A large amount of new data is available for interpretation, some of which is mentioned later.

A salient feature of the science of seeing is that of prevention (or minimization) of defective vision and unnecessary waste of human resources. It seeks to achieve this goal through the improvement of the external conditions governing visibility or the difficulty of visual tasks. To a very large extent, present knowledge of the value of improved conditions for seeing has been secured from the reactions of subjects with normal vision. A few researches[2] involving subjects of inferior vision indicate that this group receives even greater assistance from the various aids to seeing. The significance of this conclusion is obvious when it is recalled that a large part of the adult population composes the latter group. Furthermore, the new viewpoint emphasizes the artificiality of performing visual tasks within the reach of the arms.[2] Perhaps this condition should be minimized for children under ten years of age. This would mean new considerations of lighting in a school-room, for example.

An enormous amount of data pertaining to the visual sense is available from researches in physiological optics. In this paper we are confining ourselves primarily to new data involving the newly extended viewpoint of seeing.

Psychophysiological effects

In general, the physiological effects of seeing are functions of the characteristics of the visual task and all factors affecting it. These effects are less directly related to the characteristics of the general surroundings.[2] The reverse is true for the psychological effects[3] arising through the visual sense. Hence, this complex phase of seeing

divides very naturally into two components. The science of seeing has invaded each of these realms by both objective and subjective research methods.[8] However, the interpretation of subjective data by inexperienced observers often leads to erroneous conclusions, as will be shown later.

It has been possible to trace the physiological effects of seeing upon the human seeing-machine by quantitative investigations involving the pupil, the retina, the ocular muscles, the heart and finally by measurements of nervous muscular tension resulting from visual effort. While this chain or cycle of reactions is by no means a complete representation of the physiologic effects of seeing, it provides a scientific basis for the specification of visual conditions. Researches in progress or in prospect are continuing the invasion of this important realm.

The relative effects of long-continued periods of exacting visual work may be shown by measuring the changes which occur in the diameter of the pupil.[22] For example, it has been shown that a dilation of the pupil occurs as a result of a day's work involving visual effort. It is particularly significant that the relaxation afforded by a night of sleep only partially offsets this effect. Hence, the effect of close visual work, as indicated by pupillary changes, gradually increases as the work-week progresses. Considerable recuperation takes place over the week-end. These data emphasize the severity of the visual tasks of the modern work-world, and the need for establishing optimum conditions for seeing. For years in our researches we have kept in mind the possibility of the pupil size as an indicator of seeing conditions and of penalties paid by human seeing-machines. In other words, it may become an important appraiser of lighting conditions, not in the old sense of small pupils under glaring lighting but in a much more extended sense.

Since the eyes evolved under daylight levels of illumination, there are strong philosophical reasons for competing with daylight by artificial means.[2] The processes of adaptation in the retina appear to be sufficient for its protection; hence the advantages of higher levels of illumination are obtained without deleterious physiological or pathological effects. That the eyes (or retinae) are not abnormally fatigued by long periods under the usual daylight intensities of illumination is evidence that "retinal fatigue" is not a significant factor where normal eyes are concerned. Of course, quality of light is a factor which eventually must be taken into account fully before the science of

seeing is complete. Many data are already available but there are still important gaps in knowledge pertaining to quality of light and ease of seeing. Certainly no safe conclusions pertaining to quality of light suitable for continued use can be based solely upon visibility measurements which do not involve long periods of visual effort. However, this mistake has been commonly made.

There is considerable evidence to indicate that much of the strain of seeing has its origin in the functioning of the ocular muscles. Critical seeing is very largely performed at distances of approximately 14 inches. This so-called "normal distance" for close visual work is better suited to the convenience of the arms than it is to the eyes and results in abnormal demands upon the ocular muscles.[2] This handicap imposed upon the eyes by critical near work is probably the most difficult factor to minimize. However, it has been shown that the improvement in visibility produced by higher levels of illumination is obtained without an augmentation of this factor[23] and in fact, recent research data suggest that it is minimized.

In the invasion of the realm of psychophysiological effects of seeing, the most significant research so far reported involved the measurement of nervous muscular tension.[18] The results show that nervous muscular tension, originating as a result of visual effort, decreased as the intensity of illumination increased. (See Fig. 3) This research presents positive proof from extensive quantitative measurements that a visual task may be performed more easily as the conditions for seeing are improved far above the threshold conditions. The visual task which consisted of reading a book printed in 12-point type on excellent non-glossy paper, could be performed under an intensity of illumination as low as a fraction of a foot-candle. Still, it was proved that the visual task became easier and easier as the intensity of illumination increased from one to 100 foot-candles. The data indicated that at least several hundred foot-candles would be the best intensity of illumination for this task which could be performed in full moonlight. These data prove that the desirable levels of illumination are far above those practicable by many of the present lighting installations. In fact, for the first time we have quantitative data indicating that daylight intensities of illumination are ideal for human seeing-machines. This research alone revealed a new opportunity and responsibility for lighting specialists. It is responsible more than any other research for crystallizing the new viewpoint and definitely establishing a new science of lighting. At the same time it has re-

vealed the need for much new knowledge pertaining to quality of lighting.

A research recently completed and now awaiting publication establishes as a fact that a close correlation exists between the pulse or the heart-rate and the intensity of illumination under which critical visual work is performed. The results show that the normal heart-rate is altered approximately five times as much by reading for an hour under one foot-candle as it is under 100 foot-candles. These data involving the recording of nearly a million heart-beats, support the conclusions formed as a result of the research which related nervous muscular tension to intensity of illumination. This is additional evidence of the far-reaching effects of seeing upon the bodily functions. (See Fig. 3)

The psychological realm of seeing includes such factors as stimulation, confidence, impression, attitude and many others. Much of our knowledge of the influence of seeing upon these factors is inherently of subjective origin, although it is possible to make objective investigations in some of these fields. For example, the stimulating effect of light has been appraised by measuring the rate of performing a purely tactile task.[24] In this case, the stimulating effect of higher levels of illumination produced an increase in the rate of working. New data of this kind are needed and doubtless will be forthcoming as the new viewpoint of seeing filters further into the realms of physiological and psychological research.

Perhaps the most important of the psychological aspects of seeing, at least from the viewpoint of conserving human resources, is the inadequate and often erroneous appraisal of ease of seeing by subjective methods. For example, subjects commonly believe that they can see more quickly and more clearly (and interpret this as easier seeing) if the test-object is seen amid dark surroundings rather than in a field of uniform brightness. Actual measurements prove that the reverse is true.[25] In this case, the psychological factor of concentration is incorrectly interpreted by the subjects as a reaction pertaining to the efficiency of the visual functions. The failure of human seeing-machines to properly appraise conditions for seeing is largely responsible for the general satisfaction with prevalent primitive conditions for seeing.

The new science of seeing forces lighting practice into the realm of psychophysiological effects. It has been difficult for the lighting specialists to appreciate these factors but results of researches during

the past decade have contributed much helpful data. The human seeing-machine is a new conception which, when once fully grasped, makes it easy to expand the narrow and inadequate lighting viewpoint of the past into the important realm of human functions and reactions. Seeing involves more than the external realm of objects, backgrounds, light and lighting. It involves more than eyes and the visual sense. It encompasses the entire human being which is the seeing-machine. Much research must be done before the new sciences of seeing and of lighting are fully sketched. However, the major task will be accomplished when the newly extended viewpoint has been generally achieved by everyone dealing with anything involved in seeing, such as light and lighting are.

Light and Lighting

Lighting, being essential to seeing and being universally controllable, is of primary importance as a tool for decreasing the burden placed upon the visual sense and upon human beings by modern tasks of seeing. As indicated in Fig. 1, lighting may be considered as a chain of three links. It involves the physical sciences of production and control of light and the psychophysiological science of specification of light and lighting. It is a major factor in the science of seeing which is intimately related to all phases of seeing. Lighting must become a science if it is to serve mankind adequately and with certainty.

MAJOR FACTORS IN LIGHTING

A science of lighting must inevitably grow out of the new science of seeing. The latter began to develop in its proper fullness when the viewpoint of scientific research was greatly extended beyond vision into seeing. Likewise a new science of lighting must be founded upon a similarly extended viewpoint. Now light and lighting become aids to more than vision. They serve the entire human being, conserve human resources and influence human efficiency, behavior and welfare. Owing to this greatly extended viewpoint and the new concepts involved any summary of the new science of lighting must necessarily devote adequate space to the new setting and to the primarily new concepts. This leaves little space available for a discussion of light and lighting. However, this paper does not aim to be an exhaustive presentation of data but is merely a readable summary of major facts and principles which give an idea of what the new science of lighting

will be and must be. With this explanation let us consider lighting in a broad and scientific sense.

We may divide lighting into three factors. The lighting specialist may control these factors for the purpose of increasing the ease of seeing and for conserving human resources by minimizing undesirable psychophysiological effects and by creating desirable ones. These three factors or phases of lighting may be described briefly as

Quantity of light
Quality or spectral character of light
Quality of lighting.

Quantity of Light (Foot-candles)

Eventually visual tasks must be rated according to a scale of difficulty and eventually lighting recommendations must be made in accordance with such a scale.[9] Such a procedure requires adequate knowledge of the effectiveness of quantity of light as a factor in seeing. The foot-candle as a unit of quantity is merely a means to an end. It is meaningless, excepting as a physical unit, until interpreted into seeing. When this is done the foot-candle is found to be inconstant in value. Furthermore the purpose of the foot-candle is to produce brightness. Therefore, foot-candles are meaningless unless reflection-factors are specified or taken into account.[1] Whenever we use this unit it is to be understood that reflection-factors are taken into account if they are not obvious or specified.

Foot-candle recommendations of the past are inherently arbitrary values. In fact, all foot-candle recommendations are excepting those for barely seeing and for optimum ease of seeing. At present the optimum levels of illumination for most tasks are far above the range of foot-candle recommendations and in many cases are far above the practicable or attainable levels of illumination by artificial light.[3] Hence, foot-candle recommendations lower than the ideal intensities possess no inherent justification in the absolute or purely scientific sense. However, intensities of illumination which are specified in accordance with the difficulty of the visual task may be scientifically exact in a relative sense, even though they are far below the ideal levels of illumination.[10] The technique for evolving such recommendations is an important part of the science of seeing.

A conspicuous characteristic of numerous and diversified visual researches is that similar relationships are obtained between foot-candle

intensity and the various experimental criteria, such as acuity, speed of vision, nervous muscular tension, etc. Specifically, these researches indicate that intensity of illumination must be varied in geometric increments in order to secure arithmetic increments of improvement in seeing.[3] This geometric relationship of quantity of light to seeing may conveniently be termed the *foot-candle scale of effectiveness.* Although it is indeterminate as an absolute scale, *it is exact as a relative scale.* This relationship is applicable, with few exceptions, to all phases of seeing which involve foot-candles as a variable. However, in practice it is not convenient to use a scale of foot-candle effectiveness which is an exact geometric progression. Such a scale, in addition to the inconvenient divisions, would connote an unwarranted precision not suggested by round numbers. Hence, the following approximate scale of foot-candle effectiveness has been proposed[9] and is becoming accepted.

1 2 5 10 20 50 100 200 500 1000

The foot-candle steps of this scale represent approximately equal contributions to improvement in seeing. The interval between any two successive steps represents the minimum difference in level of illumination which can be justified upon the basis of an observable improvement in seeing. For example, a recommendation for an increase in intensity of illumination from 10 to 100 foot-candles is interpretable, on this scale, as an increase in seeing of three minimum steps. In general, it is practicable and permissible to state that the intensity of illumination must be doubled in order to obtain an obvious and significant improvement in seeing.

The following foot-candle recommendations for common tasks of the work-world are quite conservative from the viewpoint of the new science of seeing. They are frankly a compromise between optimum values (which are known to be much greater) and prevalent values or those obtainable satisfactorily by available installations or methods of lighting. These recommended foot-candles are far below the intensities of illumination which new knowledge indicates to be ideal but they represent a great advance over former recommendations based upon inadequate data and a restricted view-point. They are based upon the approximate geometric scale of foot-candle effectiveness combined with new knowledge pertaining to relative difficulty of visual tasks.

100 Foot-candles or More—For very severe and prolonged tasks, such as fine needlework, fine engraving, fine penwork, fine assembly, sewing on dark goods and discrimination of fine details of low contrast, as in inspection.

50 to 100 Foot-candles—For severe and prolonged tasks, such as proof-reading, drafting, difficult reading, watch repairing, fine machine-work, average sewing and other needlework.

20 to 50 Foot-candles—For moderately critical and prolonged tasks, such as clerical work, ordinary reading, common benchwork and average sewing and other needle work on light goods.

10 to 20 Foot-candles—For moderate and prolonged tasks of office and factory and when not prolonged, ordinary reading and sewing on light goods.

5 to 10 Foot-candles—For visually controlled work in which seeing is important, but more or less interrupted or casual and does not involve discrimination of fine details or low contrasts.

0 to 5 Foot-candles—The danger zone for severe visual tasks, and for quick and certain seeing. Satisfactory for perceiving larger objects and for casual seeing.

In general, the appraisal of the relationship between lighting and seeing has been based upon data from behavioristic experiments.[6] However, the subject has also been investigated by the subjective method of experimentation and both interesting and significant results have been obtained.[26] In a recent research, a large number of adult subjects were asked to select, by actual trial, the intensity of illumination considered as ideal for reading black print on white paper for long periods. The selection was made solely upon the basis of their own criteria of comfort afforded by the lighting. As shown in Fig. 3, the average intensity selected by 82 subjects was about 100 foot-candles. Owing to the indefiniteness of the criteria it is not surprising that the maximum and minimum selections were 1000 and 10 foot-candles, respectively. Such a result provides experimental evidence of the conservative character of the foot-candle recommendations presented in this discussion, although this kind of experimental attack is by no means desirable for laying a scientific foundation for lighting. In fact, human beings are very poor judges of seeing conditions. They are poor seeing-meters.[10] However, an experiment of this sort is some times of value in a corroborative sense. At least the results show that persons apparently satisfied to read under one

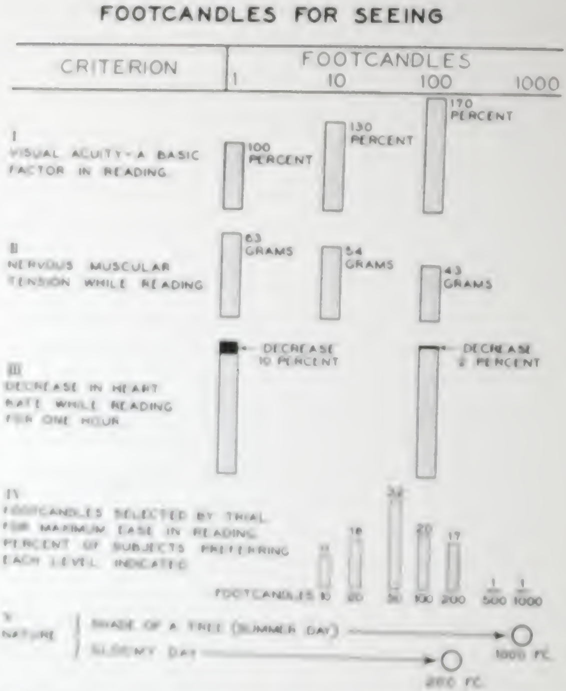

FIG. 3.—A summary of some important reactions of the human seeing-machine to quantity of light.

or two foot-candles choose an average of about 100 foot-candles if they have an opportunity and are divorced from the commonly distorted and inadequate economic considerations.

The influence of quantity of light upon seeing, in several major phases, is presented graphically in Fig. 3. It is evident that the task of reading is not only made easier by higher levels of illumination, as indicated by Item I; but also that deleterious psychophysiological effects of reading are minimized, as indicated by Items II and III. Item IV presents the results of a subjective experiment for ascertaining the intensities of illumination chosen for reading by a large group of persons having no idea of the intensities they were dealing with. Item V serves to orient the levels of illumination used in the experimental work with respect to significant levels of daylight illumination.

The foregoing are glimpses of some of the new facts and principles revealed by researches during the past decade. They reveal incon-

sistencies and inadequacies of lighting codes in which foot-candle recommendations were not founded upon a scientific basis. Certainly lighting codes should be brought up-to-date immediately. At least conservative values such as we have recommended are justifiable. A beginning should be made to base foot-candle recommendations on a scientific foundation.

Spectral Quality of Light

The determination of the influence of spectral quality of light upon seeing involves many criteria from the realms of optics, physiology, psychology and pathology. Since these various criteria not infrequently lead to contradictory conclusions, the fallacy of over-emphasizing any single criterion should be obvious. For example, it is conceivable that a spectral quality of light, which appears to be ideal when appraised by the criterion of visual acuity,[27] may not be satisfactory for the human seeing-machine operating for long periods under such an illuminant.[28] In this respect, data pertaining to the effects of spectral quality of light are more difficult to interpret into practice than those pertaining to quantity of light.

The only inherent characteristic or property of light is its spectral quality. Hence it might be supposed that this factor is of the greatest importance in seeing. Actually, experience and research indicate that it is generally of secondary importance in comparison with quantity of light, at least when foot-candle-intensities are very low compared with daylight intensities. From an analytical viewpoint, the advantages, if any, of a specific spectral quality of light correspond with the degree to which the light approaches either monochromaticity as one extreme or natural daylight as the other, depending upon the character of these advantages.

The appraisal of visual efficiency is perhaps the most obvious of the various methods for determining the influence of spectral quality of light upon seeing.[29] For this purpose, visual acuity, speed of retinal impression and contrast sensitivity are available as criteria. In general, research data indicate that visual acuity is increased as the light approaches monochromaticity. This is due chiefly to the minimization of chromatic aberration. Usually, speed of retinal impression or "speed of vision" is not primarily or inherently a function of the spectral quality of light, at least not in a practical sense. It may be important when the time available for seeing is less than

0.1 second. However, it is reasonably safe to conclude that spectral quality of light, when appraised by the criteria of physiologic optics, is a secondary factor in the usual tasks of the work-world where color is a secondary matter. Of course, it may be a factor of considerable importance when it materially affects the color and brightness of colored objects. But even these influences are usually of minor magnitude when the intensity of illumination is adequate from the new viewpoint of easy seeing.

Brightness-contrasts and color-contrasts may be appreciably altered, or even eliminated, by changes in the spectral quality of the incident light.[28] With few exceptions, white light or average daylight has all the force of logic on its side as an illuminant for general use. Some data indicate that quality of light, at least for illuminants which would be considered for lighting purposes, is not important from the viewpoint of ease of seeing. However, more elaborate investigation of this aspect is needed.

There is some evidence, largely of a subjective character, which indicates, at least in certain anomalous cases of vision, that the eyes tire more quickly while functioning under the yellowish light from tungsten filaments than under natural daylight.[3] This evidence is in harmony with the philosophy that the ideal quality (or quantity) of light is that quality (or quantity) under which the eyes evolved. However, other variables are usually present so that the cause of the apparent fatigue is not certain. It is conceivable that some advantage in minimizing eye-fatigue might be secured by a reduction of the infra-red radiation reaching the eyes.[31] Even humidity may be a factor in eye-comfort. At the present time there are very few dependable data pertaining to pathological or physiological effects of particular qualities of light upon the eyes.

It is in the psychological realm of seeing that the factor of quality of light plays a rôle of known importance. The impressions created by lighting are definitely related to the spectral quality of the light. In the home, for example, artificial daylight at night appears cold and bluish, though it is not; and we may be hurt esthetically.[32] In contrast, the warm yellowish light of flames creates the impression of comfort and cheer. These impressions are typical of countless others which arise from psychological causes.[3] The eyes are doorways of impressions as well as tools for seeing. The psychological effects lead the investigator far into complex fields which cannot be discussed in a brief space.

Quality of light or spectral character may become of more importance when levels of illumination in general use have reached values more in line with those desirable for easy seeing. Certainly in a half-seeing world, engaged in the severe visual tasks of civilization under intensities of illumination of a few foot-candles, spectral character of light is of secondary importance at present. The exceptions are the exceptional cases of seeing, not the usual ones. Of course, when lighting for seeing has made adequate progress beyond the primitive present, quality of light will offer many opportunities for refinement in the service of light to seeing.

Quality of Lighting

This is unquestionably the most intricate phase of lighting. Various factors are involved in an infinite variety of combinations. The factors are difficult to describe and define compared with the simplicity of the foot-candle. Considering the amount of new research necessary to place foot-candle recommendations upon its present scientific though incomplete basis, it should be obvious that an enormous amount of similar research will be necessary before quality of lighting will become an organized part of lighting. From the viewpoint of scientific knowledge this realm is a tangled jungle. However, data are available for invading it systematically.

Quality of lighting essentially involves the distribution of brightness (or color) in the visual field. The components of brightness in the visual field may be subdivided into three groups. These pertain to

The light-sources
The immediate visual field (the visual task)
The general surroundings.

We are interested in these brightnesses in both the absolute and relative sense. Absolute brightness is important chiefly from the viewpoint of threshold sensibility or in the case of primary glare. Usually we are interested in the distribution of relative brightness, as for example, the brightness of a printed page compared with that of the surroundings.[5]

The three components of brightness involved in quality of lighting are inter-related. Hence, each complexity may be combined with the others to form a supercomplexity. Of course we know when the quality of lighting is distinctly bad but unfortunately we cannot

judge with certainty when it is good or ideal. Here again it is emphasized that human beings are poor seeing-meters. In this aspect of lighting and seeing correlations established between visibility and ease of seeing are of tremendous significance and assistance. Present knowledge of the relationships involved in quality of lighting is very largely of a qualitative character, although a good beginning has been made in obtaining quantitative data.

The available experimental data pertaining to quality of lighting is not as meager as it is uncorrelated. A few correlations among such factors as glare, visibility and ease of seeing would work wonders. A similar situation existed with respect to quantity of light or foot-candles before various unrelated investigations of certain fundamental factors were replaced by extensive and coordinated researches involving all critical factors. In general, the quantitative data which are available usually involve a consideration of one, and seldom more than two of the three principle components of quality of lighting. The inadequacy of present knowledge is attested by the fact that science has not yet supplied dependable quantitative data upon which to specify ideal brightness-relationships, even for such a universal task as reading. We know when the brightness-contrast between the page and the surroundings is obviously annoying but we know only roughly the permissible limit. The new research technique which has opened such new vistas in respect to quantity of light must be applied to the common factors involved in quality of lighting.

Relatively satisfactory data are available for the specification of quantity of light for a particular task, but much remains arbitrary or empirical in the method of supplying light. A recent research[33] indicates that light-sources of small area of high brightness and large areas of low brightness, respectively, are most effective on the basis of admitting light to the retina. The analysis was made upon the basis of equal intensities of illumination at the eyes and their effect upon the size of the pupil. These data also indicate that a circular light-source subtending an angle of 17 degrees at the eyes is least effective in this respect. That is, the pupil is smallest under this combination of area and brightness of the light-source or luminous surface. It is equally logical to conclude from these data that the pupillary mechanism is of maximum effectiveness as a protecting device for a light-source of this size. Such data are interesting from the viewpoint of prevalent ideas pertaining to socalled indirect and direct lighting systems.

The brightness-relationships associated with light-sources may also be determined from appraisals of the effects of glare. Fundamentally, glare may be considered as a subjective phenomenon which may cause deep-seated and even detrimental effects. Glare has been proved to cause nervous muscular tension just as low levels of illumination do.[34] For example, a glare-source at 20 degrees from the line of vision and providing 5 foot-candles at the eyes and 5 foot-candles upon the visual task produced the same degree of nervous muscular tension as was produced when performing the same visual task illuminated by one foot-candle and without glare. In this respect the glare condition wasted 80 per cent of the illumination supplied to the visual task.

This research reveals the deep-seated effects of glare. Knowing what we do about the influence of poor seeing upon nervous muscular tension and heart-rate it can be concluded with assurance that poor quality of lighting produces effects as deep-seated as those associated with less than optimum values of quantity of light. In other words, we have opened the door to the same kind of new vista for quality of lighting as for quantity of light. Doubtless the same door will also be opened for quality of light.

Owing to the subjective nature of glare, measurements of visibility have been widely resorted to and, as a consequence, glare and visibility have become related in a confused manner. It seems reasonable to associate visibility to the object and glare to the human seeing-machine. A reduction in visibility[35] may be considered an effect which occurs simultaneously with glare but not necessarily a direct result of glare. Its origin may be traceable largely to physical and physiological causes.

It has been established that the sensation of discomfort due to a glare-source is a function both of its intrinsic brightness as well as to the intensity of illumination at the eyes due to the glare-source.[36] Reduction in visibility due to a glare-source involves, in general, only the latter factor. These generalizations apply over a great range of angles of the glare-source from the line of vision. However, it is possible that, as in many other cases, this generalization breaks down for angles very close to the line of vision, that is, within a degree. This is the condition on a highway when it is necessary to see an object close to an automobile headlamp which is far enough away so that the glare-source is within a degree or so of the line of vision. This limiting case needs further study from various viewpoints.

Since it is extremely difficult to obtain dependable quantitative data by subjective criteria, the appraisal of the effects of glare is a tedious means of determining brightness-relationships pertaining to light-sources, whether they are primary sources or illuminated areas. That this factor cannot be ignored emphasizes the complexities encountered in developing a science of lighting.

The technique involved in the lighting of the immediate visual field (the visual task) is relatively simple where two-dimensional objects are to be seen, as in reading. In this case, it has been established that a visual field of uniform brightness is usually desirable. If three-dimensional objects are to be seen, such factors as diffusion and direction become highly important. High-lights and shadows play important parts in seeing such objects.[37] Such factors as specular reflection may be either an advantage or a handicap in the individual case. These phases of quality of lighting are difficult to discuss briefly owing to lack of simple terms and to the absence of adequate correlations of the various factors.

The influence of the quality of lighting extends not only into the psychological realm of impression,[38] but also into the physiological realm pertaining to ease of seeing. Frequently, in the performance of visual work, the attention is shifted from the details of the immediate visual task to those of the general surroundings. This change in fixation relieves the strain upon the muscles of accommodation and convergence which is created by near-visual work. Obviously, it also affords a certain degree of mental relaxation. If, during these rest-periods, the eyes are forced to adapt themselves to radically different brightness-levels, the benefits from such periods are minimized. Although a direct quantitative appraisal of the psycho-physiological effect resulting from sharp changes in adaptation has not been made, the subject may be approached indirectly. It has been shown, for example, that visual efficiency is definitely lowered in situations where the eyes must alternate between areas of different brightnesses.[39]

Even though fixation is maintained within the immediate visual field, the lighting of the surroundings influences visual efficiency. For example, it has been demonstrated that the precision with which visually controlled operations could be performed was significantly decreased when the surroundings were darkened.[40] Similar deleterious effects of dark surroundings were obtained when speed of vision was taken as the criterion.[41] In a strict sense, researches of this type

pertain solely to visibility, but correlations between visibility and ease of seeing add enormously to their value as indirect but dependable appraisals of complex psychophysiological effects.[10]

Strictly considered, lighting is not practiced when only quantity of light is supplied upon a horizontal plane. The simplicity of illuminating large areas by means of general lighting from indirect, semi-indirect or direct systems has confined practice too much to these systems. An intimate study of seeing and the human seeing-machine leads to the conclusion that general lighting alone does not meet the requirements in most cases. The science of seeing has already shown that prevalent intensities of illumination indoors in daytime and almost everywhere at night are very inadequate. *General lighting plus* supplementary lighting[5] offers a practicable means for obtaining the levels of illumination to which the eyes are entitled. At the same time, this method introduces lighting where only light has been generally supplied. This method not only makes it possible to obtain, or at least to approach, optimum visibility conditions and maximum ease of seeing. It also makes it possible to provide favorable conditions for visual relaxation or visual concentration as desired.

The application of the foot-candle scale of effectiveness as a guide for general and supplementary lighting components simplifies the design of such installations.[10] To any level of general lighting may be added one, two or three steps of supplementary lighting in accordance with the *safe* rule that the brightness of the immediate field may be ten times as great as that of the surroundings without imposing serious negative effects. In many cases, the ratio may be considerably higher, depending upon the reflection-factors, the extent of the brighter field, and the visual requirements of the task.

It is a simple matter to measure quantity of light, but it is difficult to appraise quality of lighting. To a large extent a knowledge of seeing in all of its complex and inter-related phases must substitute for instruments. Eventually, much of the qualitative knowledge of the factors involved will be replaced by quantitative data and the problem will be simplified correspondingly. Also new terminology and units should be made available for dealing with the important factors involved in quality of lighting.

A LIGHTING CONSCIOUSNESS AWAKENS

Seeing is the most universally important activity of human beings and light is just as essential in seeing as eyesight is. Artificial light is

a major factor in making our civilization possible. In the past fifty years, since the advent of electric light, great progress has been made in the production and control of artificial light. In fact, this progress is one of the outstanding services of modern science to modern civilization. The uses of artificial light have multiplied rapidly. They have extended man's independence greatly. Through them civilized activity is continuous wherever desired. Still, notwithstanding the super-importance of light and lighting, their essentiality and potentiality, and their manifold services to mankind, a lighting consciousness does not generally exist. Indeed, it is relatively rare. Commonly it has not seriously entered into the considerations of a civilization which would slow down almost to a standstill without light. Relatively rarely is lighting a factor in the outlook of those who are responsible for the welfare of family, workers and public. In brief, light either has been ignored or incidentally considered compared with its major importance. At best, a lighting consciousness only feebly asserts itself and then, naturally, it is concerned with barely seeing instead of seeing easily, quickly and accurately.

Well may the lighting specialist and the lighting industry inquire into the matter. Considering the great importance of lighting and the enormous expenditure of resources in the development and promotion of artificial lighting, the general absence of a lighting consciousness is a matter worthy of serious inquiry. This state of affairs has often been considered as an indictment of the lighting business or of some part of it such as lighting specialists. We might break down the lighting business into producers of light-sources, lighting equipment and electrical energy and examine in detail their past efforts. We might critically examine the preachings and practices of lighting specialists. Doubtless in such a critical analysis no group would be found to have made a perfect score. But the shortcomings of lighting development revealed by such a survey scarcely would be of such a magnitude as to account adequately for the general lack of consciousness of light and lighting which are so essential and important to every civilized human being excepting the unfortunately blind. An adequate answer must be sought for elsewhere.

We believe the answer is largely to be found in the fact that lighting practice in the past has not had the knowledge available to make light and lighting intimate factors in the efficiency, behavior and welfare of human beings. In some minor phases of production and safety some statistical data have been brought to bear. But production and

safety are important only in a very small part of all the countless moments of civilized activity. Lighting practice has been largely concerned with the production and control of artificial light. This is the strictly engineering realm. Not a human element of any kind, as far as the user of light is concerned, is involved in these two links of the chain of lighting. (See Figs. 1 and 2.) Lighting practice which runs out of sound scientific knowledge at the fixtures, or when the lighting has been installed, has made little or no contact with the human users of the light. Under such circumstances lighting makes little impression upon them. Appeal may be created through emotional channels, but only scientific knowledge is convincing. Human beings are conscious of the bad and not the good in lighting. They are conscious of the absence, inadequacy, or other obvious faultiness of light and lighting. They must be taught that complex scientific method alone can reveal what is best for them. They must acquire a faith in modern science in lighting practice as in medical and other practices.

Only recently has the forging of the third link—specification of light and lighting—been begun in earnest. It is one of the products of the science of seeing. It is this link which makes lighting intimate with human beings. This link completes the chain beginning with light production and ending in human efficiency, behavior and welfare. This is the psychophysiological link which specifies light and lighting for human seeing-machines. The science of seeing is forging this link by means of researches which relate light and lighting with the muscular, neural and mental processes of human beings, that is, with human organs, bodies and minds. This is an important part of the scope of the new science of seeing. By no means is the third link in the chain complete, but much knowledge is now available which has not yet entered seriously into lighting practice. It can only do so through a new science of lighting. But recently a beginning has been made and, though meager and halting as the first steps must be, it is obvious that a lighting consciousness is awakening as never before. This lends strength to the contention that a lighting consciousness could not develop in the past because of a lack of convincing knowledge which means sound scientific knowledge.

Let us view this matter from one other angle in completing this sketchy picture of a subject of over-all importance—lighting consciousness. As human seeing-machines we are interested in the visual task, the visual sense, and the lighting. When the science of seeing

awakens a seeing consciousness, the human seeing-machine asks, How can seeing be improved for me? From the new viewpoint of seeing, controllability of the factors involved determines their importance, because it determines what can be done to improve seeing. Someone somewhere may have control over the visual task itself, but relatively little control can be generally exercised over it. Usually we must accept the visual tasks as they are physically. The same is true of the visual sense. It has certain abilities and limitations. Of course, if there are optical defects, proper eye-glasses should be used to counterbalance them. Eye-specialists are well prepared to do this. However, light is generally controllable by the human seeing-machine or by someone within easy reach. Light is not only essential but highly controllable. Thus lighting is elevated from insignificance to a major rôle. Briefly such an approach through the science of seeing reveals why the latter can, and is, developing a lighting consciousness. A seeing consciousness, when aroused, in turn arouses a lighting consciousness. They go hand in hand.

AN ADDITION TO SOCIAL SCIENCE

In this sketch of the new science of lighting it is seen that human welfare is emphasized. In fact, the science of seeing is largely the extension of the older viewpoint of lighting and vision as tools into the psychophysiological realm of human beings; and, therefore, into the realm of end-products such as human efficiency, behavior, health, safety and welfare. Lighting for seeing aims to reduce the costs of seeing to human beings. These costs are not only in impaired eyesight and bodily disorders resulting from eyestrain. These have long been known but the recently extended viewpoint from vision as a tool, into seeing as an activity which affects the neural, muscular and mental processes of human organisms throws new light upon them. It reveals a goal which encompasses the unobvious as well as the obvious. To see most easily instead of to barely see is the new goal. This means the minimization of heretofore hidden wastes as well as eye-strain disorders. It means human welfare in an all-inclusive sense.

The social scientist has heretofore ignored or inadequately considered the costs of poor seeing in his elaborate studies of work conditions, rest-periods, hygiene, and other welfare aspects of human beings. The new knowledge already added to those older aspects of the science of seeing, which have been developing for a long time,

will not continue to be ignored. Seeing in its broader aspects is now shown to be a drain upon human resources in ways heretofore hidden or unobvious. As seeing in this new and more extensive sense is comprehended by the social scientist, light and lighting will receive the consideration they deserve. Thus lighting becomes a part of social science. There are powerful indications that civilization is entering an era in which social science will be very important. The development of a new science of lighting is the best assurance that lighting will attain the important place it deserves in civilization.

This is an encouraging outlook for lighting development. It is a goal worth striving for and one to be proud of. But lighting specialists need not wait for social scientists to do this work or for social science to absorb lighting. The lighting specialist who becomes a seeing specialist and applies the new sciences of seeing and of lighting is practicing this part of social science. Eye specialists have the same opportunity and responsibility. Already they are extending their interest seriously into seeing and, therefore, into lighting. They have long been a part of social science and they are beginning to recognize lighting as a valuable ally in their activities.

A new science of lighting calls for a new economics of lighting—an economics founded upon the welfare of human beings. Lighting should no longer be appraised by the useful output of the worker. This involves the welfare of the employer rather than that of the worker. Lighting must be appraised by the hidden costs or savings in human resources in homes and in schools, in traffic and in the work-world, and everywhere throughout civilized activity. Obviously the extended viewpoint of seeing reveals a widespread need for scrapping old ideas of cost of lighting and for revising lighting economics in terms of newly revealed *values* of light and lighting in the realm of human welfare.

THE PROFESSIONAL STATUS OF LIGHTING

Lighting has not reached the status of a profession in the usual sense. This statement should offend no one for it is a fact for which no one can be blamed. Space does not permit quibbling over the matter of professional status; however, in passing, we may wonder why some services to mankind are classed as professions and others equally important are not. Certainly lighting has not been classed as a profession in the usual sense and it has had no right to be. Owing to the great lack of sound scientific knowledge upon which to base

the specification of light, lighting practice has been largely a matter of salesmanship. It has scarcely been based upon specifications in a sound sense. It has been largely a matter of supplying what users thought they needed or what they would buy. At best lighting practice has supplied some improvement over what users of light had previously endured or were used to. Without scientific knowledge for specifying light and lighting upon a true basis of *value to human seeing-machines*, lighting practice cannot be elevated to the status of a profession. However, the science of seeing promises such an opportunity. Certainly, no greater service to human beings throughout civilization can be rendered than that of providing for quick, accurate, safe and easy seeing which minimizes the wastes of human resources. Such a service should place the lighting specialist, or rather the seeing specialist, on the same elevated plane as the eye specialist, physician, health official, social scientist and many others whose activities are primarily directed toward human welfare and the conservation of human resources. These enjoy a professional status worthy of their services to mankind. So can the practitioners of the new science of lighting aspire to such a level. This is a modest aspiration well within their rights. Certainly it is a worthy goal. Far off and idealistic? We do not believe so. But like all worthy goals it will require effort and resources to reach it.

REFERENCES

1. Light and Work, M. Luckiesh, *D. Van Nostrand Company*, New York, 1924.
2. Seeing and Human Welfare, M. Luckiesh, *Williams & Wilkins Company*, Baltimore, 1934.
3. Seeing—A Partnership of Lighting and Vision, M. Luckiesh and Frank K. Moss, *Williams & Wilkins Company*, Baltimore, 1931.
4. Contributions to the Lighting Art from Researches in Light and Vision, M. Luckiesh, *Proceedings, International Congress on Illumination*, 1928, 936.
5. General Lighting Plus, M. Luckiesh, *Trans. I. E. S.*, 24, 1929, 233.
6. The New Science of Seeing, M. Luckiesh and Frank K. Moss, *Trans. I. E. S.*, 25, 1930, 15; *Annals of Distinguished Service Foundation of Optometry*, 1, 1932, 6.

   Researches in Seeing, M. Luckiesh and Frank K. Moss, *American Journal of Ophthalmology*, 15, 1932, 801.
7. Lighting Plus Vision Equals Seeing, M. Luckiesh and Frank K. Moss, *Trans. I. E. S.*, 25, 1930, 807.
8. The Human Seeing-Machine, M. Luckiesh and Frank K. Moss, *Trans. I. E. S.*, 27, 1932, 699; *Jour. Fran. Inst.*, 215, 1933, 629.
9. Recommended Foot-candles, M. Luckiesh and Frank K. Moss, *Trans. I. E. S.*, 26, 1931, 1061.
10. The Applied Science of Seeing, M. Luckiesh and Frank K. Moss, *Trans. I. E. S.*, 28, 1933, 842.
11. Seeing and Highway Safety, M. Luckiesh, *National Safety News*, 28, 1933, 33.
12. Humanitarian Foot-candles, M. Luckiesh and Frank K. Moss, *Proc. I. C. I.*, 1, 1931, 76.
13. Lighting Revolutionized by Science of Seeing, M. Luckiesh, *Electrical World*, 103, 1934, 263.
14. The Dependency of Visual Acuity Upon Stimulus Distance, M. Luckiesh and Frank K. Moss, *Jour. Opt. Soc. Amer.*, 23, 1933, 25.
15. The Fixational Pause of the Eyes, P. W. Cobb and Frank K. Moss, *Jour. Exper. Psych.*, 9, 1926, 359.
16. The Four Variables of the Visual Threshold, P. W. Cobb and Frank K. Moss, *Jour. Fran. Inst.*, 205, 1928, 831.
17. The Relation Between Extent and Contrast in the Liminal Stimulus for Vision, P. W. Cobb and Frank K. Moss, *Jour. Exper. Psych.*, 10, 1927, 350.
18. A Correlation Between Illumination Intensity and Nervous Muscular Tension Resulting from Visual Effort, M. Luckiesh and Frank K. Moss, *Jour. Exper. Psych.*, 16, 1933, 540.
19. The Ability of the Eyes to Compensate for Poor Visual Conditions, P. W. Cobb and Frank K. Moss, *Jour. Fran. Inst.*, 205, 1928, 131.
20. Lighting for Production, P. W. Cobb, *Trans. I. E. S.*, 21, 1926, 35.
21. A Correlation Between Pupillary Area and Retinal Sensibility, M. Luckiesh and Frank K. Moss, *Amer. Jour. Ophth.*, 1934.

22. Size of Pupil as a Possible Index of Ocular Fatigue, M. Luckiesh and Frank K. Moss, *Amer. Jour. Ophth.*, 16, 1933, 393.
23. Eye-Fatigue and Its Relation to Light and Work, P. W. Cobb and Frank K. Moss, *Jour. Fran. Inst.*, 200, 1925, 239.
24. The Dynamogenic Influence of Light on Tactile Discrimination, H. M. Johnson, *Psychobiology* II, 1920, 351.
25. The Effect of Dark Surroundings Upon Vision, P. W. Cobb and Frank K. Moss, *Jour. Fran. Inst.*, 206, 1928, 827.
26. Illumination Intensities Chosen for Reading, M. Luckiesh and A. H. Taylor, *Trans. I. E. S.*, 17, 1922, 269.
27. Visual Acuity and Sodium-Vapor Light, M. Luckiesh and Frank K. Moss. *Jour. Fran. Inst.*, 215, 1933, 401.
28. Seeing in Sodium-Vapor Light, M. Luckiesh and Frank K. Moss, *Jour. Opt. Soc.*, 24, 1934, 5.
29. The Influence of Spectral Character of Light on the Effectiveness of Illumination, M. Luckiesh, *Trans. I. E. S.*, 7, 1912, 135.
30. Color and Its Applications, M. Luckiesh; *D. Van Nostrand Co.*, New York, 1915–1921.
31. Infrared Radiant Energy and the Eye, M. Luckiesh, *Amer. Jour. Physiol.*, 50, 1919, 383.
32. Lighting the Home, M. Luckiesh, *the Century Co.*, New York, 1920. Work-World Environments, M. Luckiesh, *Mechanical Engineering*, July 1931, 514.
33. Area and Brightness of Stimulus Related to the Pupillary Light Reflex, M. Luckiesh and Frank K. Moss, *Jour. Opt. Soc.*, 24, 1934, 130.
34. Muscular Tension Resulting From Glare, M. Luckiesh and Frank K. Moss, *Jour. Gen. Psychol.*, 8, 1933, 455.
35. Glare and the Four Fundamental Factors in Vision, P. W. Cobb and Frank K. Moss, *Trans. I. E. S.*, 23, 1928, 1104.
36. Glare and Visibility, M. Luckiesh and L. L. Holladay, *Trans. I. E. S.*, 20, 1925, 221.
37. Light and Shade and Their Application, M. Luckiesh, *D. Van Nostrand Co.*, New York, 1916.
38. Artificial Light—Its Influence on Civilization, M. Luckiesh, *the Century Company*, New York, 1916.
39. The Rate of Visual Work on Alternating Fields of Different Brightnesses, M. Luckiesh and Frank K. Moss, *Jour. Fran. Inst.*, 200, 1925, 731.
40. The Effect of Brightness on the Precision of Visually Controlled Operations, P. W. Cobb and Frank K. Moss, *Jour. Fran. Inst.*, 199, 1925, 507.
41. Some Experiments on the Speed of Vision, P. W. Cobb, *Trans. I. E. S.*, 19, 1924, 150.

GE